

## Unit 3: Atomic Structure

### Basics of the Atom

Particle	Charge	Location in the Atom	Mass
proton	1+	in nucleus	~1 a.m.u.
neutron	0	in nucleus	~1 a.m.u.
electron	1-	orbits nucleus	~0 a.m.u.

a.m.u.: unit used to measure mass of atoms

atomic number: # of  $p^+$

- the whole number on Periodic Table
- determines identity of atom

mass number: (# of  $p^+$ ) + (# of  $n^0$ )

To find net charge on an atom, consider  $p^+$  and  $e^-$ .

ion: a charged atom

anion: a (-) ion

-- more  $e^-$  than  $p^+$

-- formed when

atoms gain  $e^-$

cation: a (+) ion

-- more  $p^+$  than  $e^-$

-- formed when

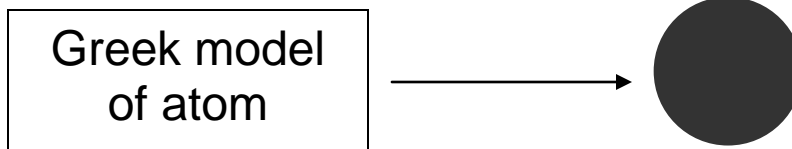
atoms lose  $e^-$

Description	Net Charge	Atomic Number	Mass Number	Ion Symbol
15 $p^+$ 16 $n^0$ 18 $e^-$				
38 $p^+$ 50 $n^0$ 36 $e^-$				
			128	$Te^{2-}$
18 $e^-$	1+		39	

## Historical Development of the Atomic Model

### □ **Greeks (~400 B.C.E.)**

Matter is discontinuous (i.e., “grainy”).



### □ **Hints at the Scientific Atom**

\*\* Antoine Lavoisier: law of conservation of mass

\*\* Joseph Proust (1799)

law of definite proportions: every compound has  
a fixed proportion

e.g., water.....8 g O, 1 g H

chromium (II) oxide.....13 g Cr, 4 g O

\*\* John Dalton (1803)

law of multiple proportions: When two different  
compounds have same two elements, equal  
mass of one element results in integer  
multiple of mass of other.

e.g., water.....8 g O, 1 g H

hydrogen peroxide.....16 g O, 1 g H

e.g., chromium (II) oxide.....13 g Cr, 4 g O

chromium (VI) oxide.....13 g Cr, 12 g O

## ***John Dalton's Atomic Theory (1808)***



1. Elements are made of indivisible particles called atoms.



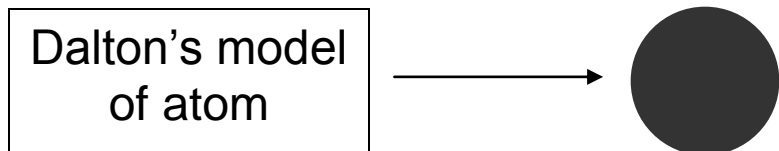
2. Atoms of the same element are exactly alike; in particular, they have the same mass.



3. Compounds are formed by the joining of atoms of two or more elements in fixed, whole number ratios.

e.g., 1:1, 2:1, 3:1, 2:3, 1:2:1

Dalton's was the first atomic theory that had evidence to support it.



\*\* William Crookes (1870s)

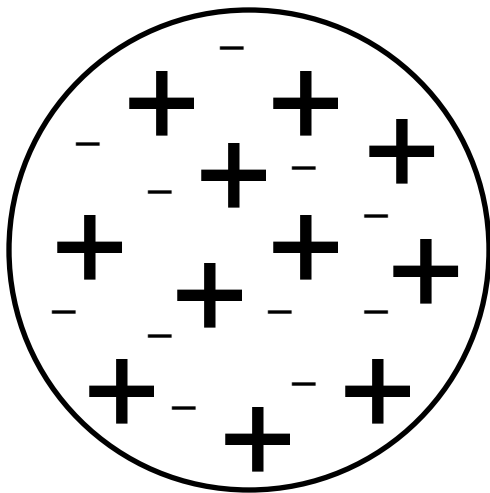
Rays causing shadow were emitted from cathode.

□ **The Thomsons (~1900)**

J.J. Thomson discovered that “cathode rays” are...  
...deflected by electric and magnetic fields  
...(-) particles → “electrons”

William Thomson (a.k.a., Lord Kelvin)

Since atom was known to be electrically neutral, he proposed the plum pudding model.



- Equal quantities of (+) and (-) charge distributed uniformly in atom.
- (+) is ~2000X more massive than (-)

\*\* James Chadwick discovered neutrons in 1932.

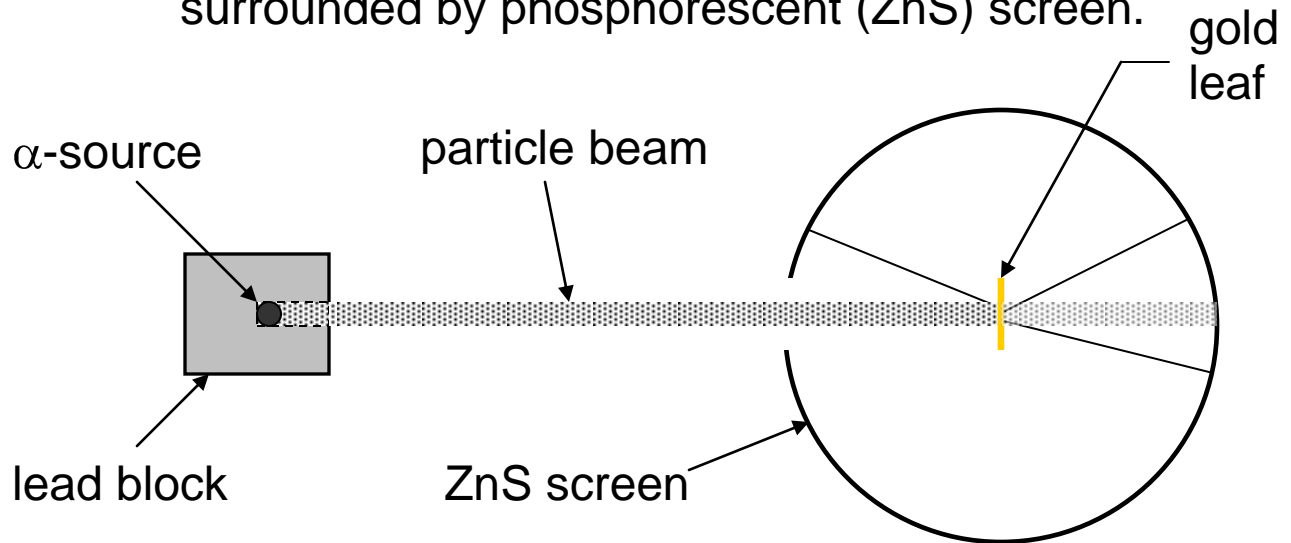
--  $n^0$  have no charge and are hard to detect

-- purpose of  $n^0$  = stability of nucleus

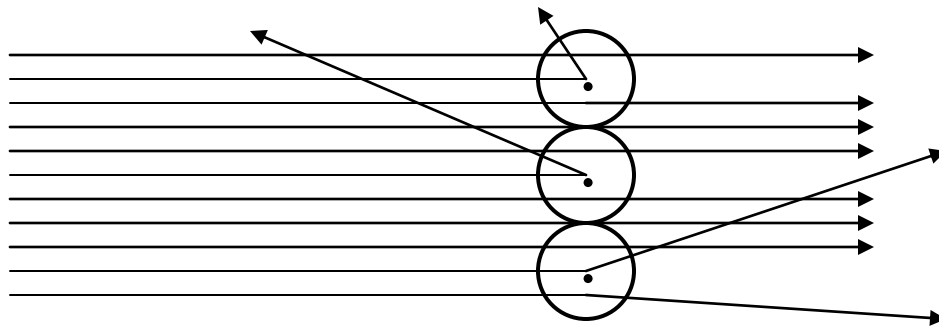
▫ **Ernest Rutherford (1909)**

Gold Leaf Experiment

Beam of  $\alpha$ -particles (+) directed at gold leaf surrounded by phosphorescent (ZnS) screen.

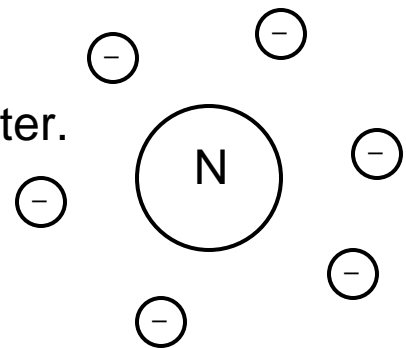


Most  $\alpha$ -particles passed through, some angled slightly, and a tiny fraction bounced back.



Conclusions:

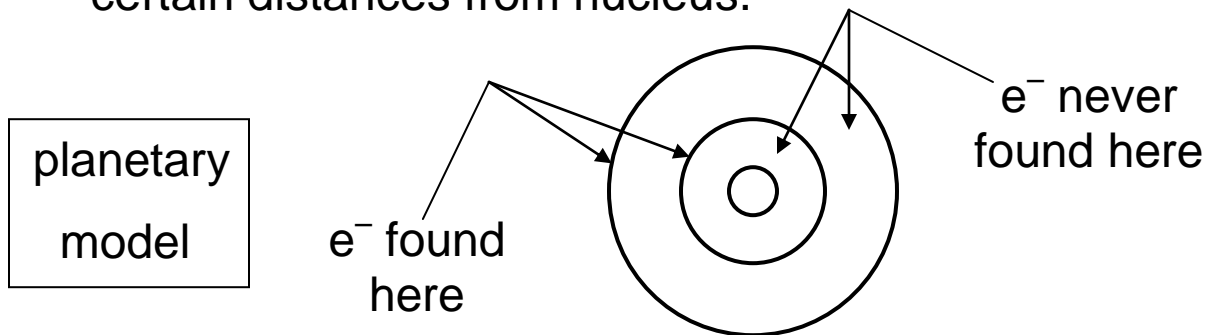
1. Atom is mostly empty space.
2. (+) particles are concentrated at center.  
nucleus = "little nut"
3. (-) particles orbit nucleus.



□ **Recent Atomic Models**

Max Planck (1900): proposed that amounts of energy are quantized → only certain values are allowed

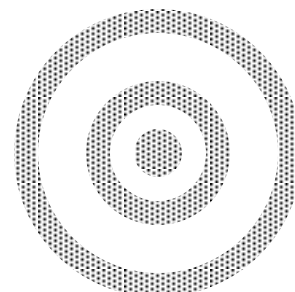
Niels Bohr (1913):  $e^-$  can possess only certain amounts of energy, and can therefore be only certain distances from nucleus.



Schrödinger, Pauli, Heisenberg, Dirac (up to 1940):

According to the QMM, we never know for certain where the  $e^-$  are in an atom, but the equations of the QMM tell us the probability that we will find an electron at a certain distance from the nucleus.

quantum mechanical model  
electron cloud model  
charge cloud model



▫ **Biology Experiment**

To conduct a biology experiment, you need 100 mL of cola per trial, and you plan to conduct 500 trials.

If 1 can contains 355 mL of cola,  
and there are 24 cans in a case,  
and each case sells for \$4.89,  
and there is 7.75% sales tax...

A. How many cases must you buy?

$$\begin{aligned} X \text{ cases} &= 50,000 \text{ mL} \left( \frac{1 \text{ can}}{355 \text{ mL}} \right) \left( \frac{1 \text{ case}}{24 \text{ cans}} \right) = 5.86 \text{ cases} \\ &= \boxed{6 \text{ cases}} \end{aligned}$$

B. How much will the cola cost?

$$\begin{aligned} X \$ &= 6 \text{ cases} \left( \frac{\$4.89}{1 \text{ case}} \right) (1.0775) = \$31.61385 \\ &= \boxed{\$31.61} \end{aligned}$$

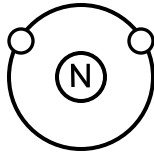
(QUANTIZED VALUES)



▫ **Light**

When all  $e^-$  are in lowest possible energy state, an atom is in the ground state.

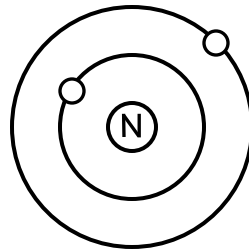
e.g., He:  $1s^2$



← ENERGY (HEAT, LIGHT, ELEC., ETC.)

If “right” amount of energy is absorbed by an  $e^-$ , it can “jump” to a higher energy level. This is an unstable, momentary condition called the excited state.

e.g., He:  $1s^1 2s^1$



When  $e^-$  falls back to a lower-energy, more stable orbital (it might be the orbital it started out in, but it might not), atom releases the “right” amount of energy as light.



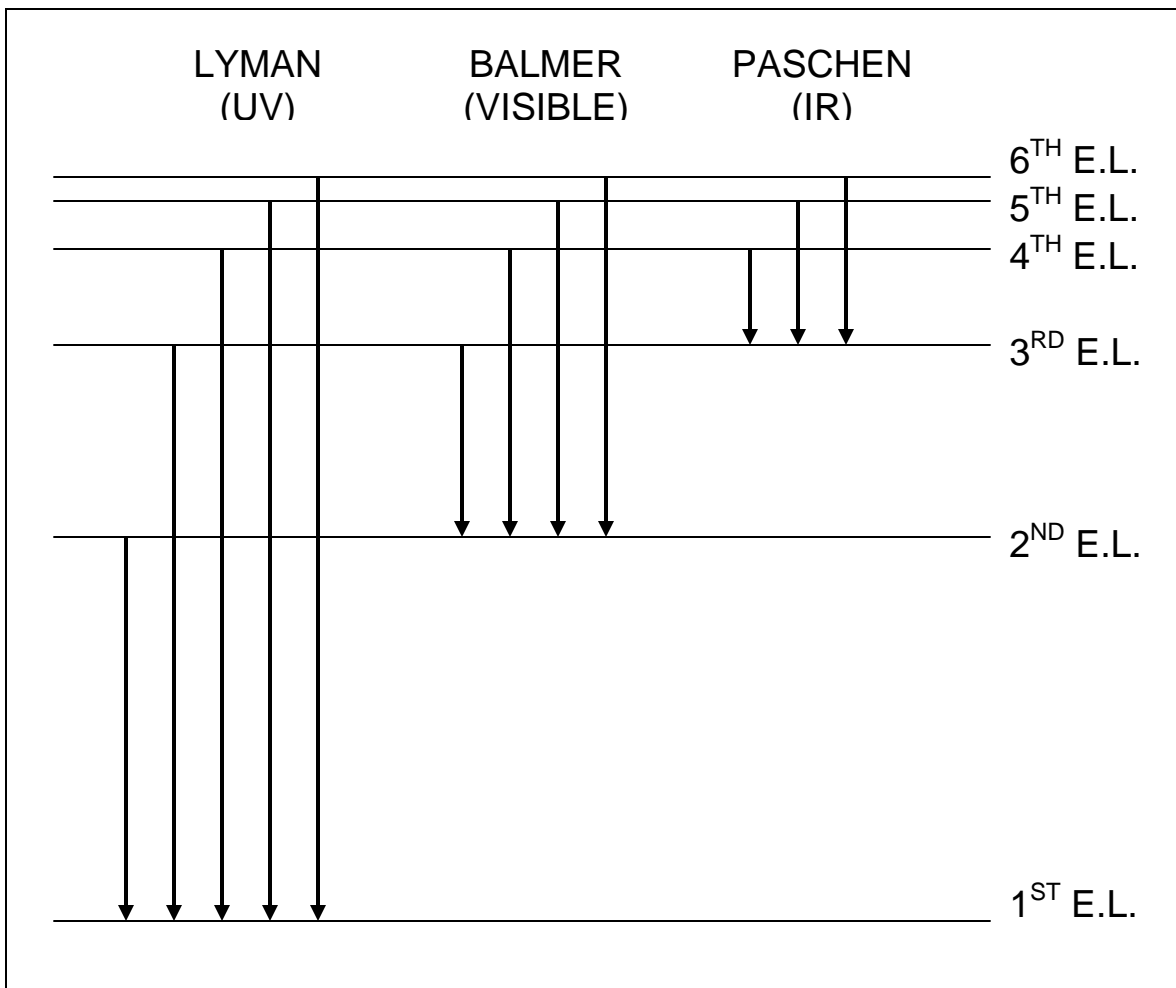
Any-old-value of energy to be absorbed or released is NOT OK. This explains the lines of color in an emission spectrum.

□ **Emission Spectrum for a Hydrogen Atom**

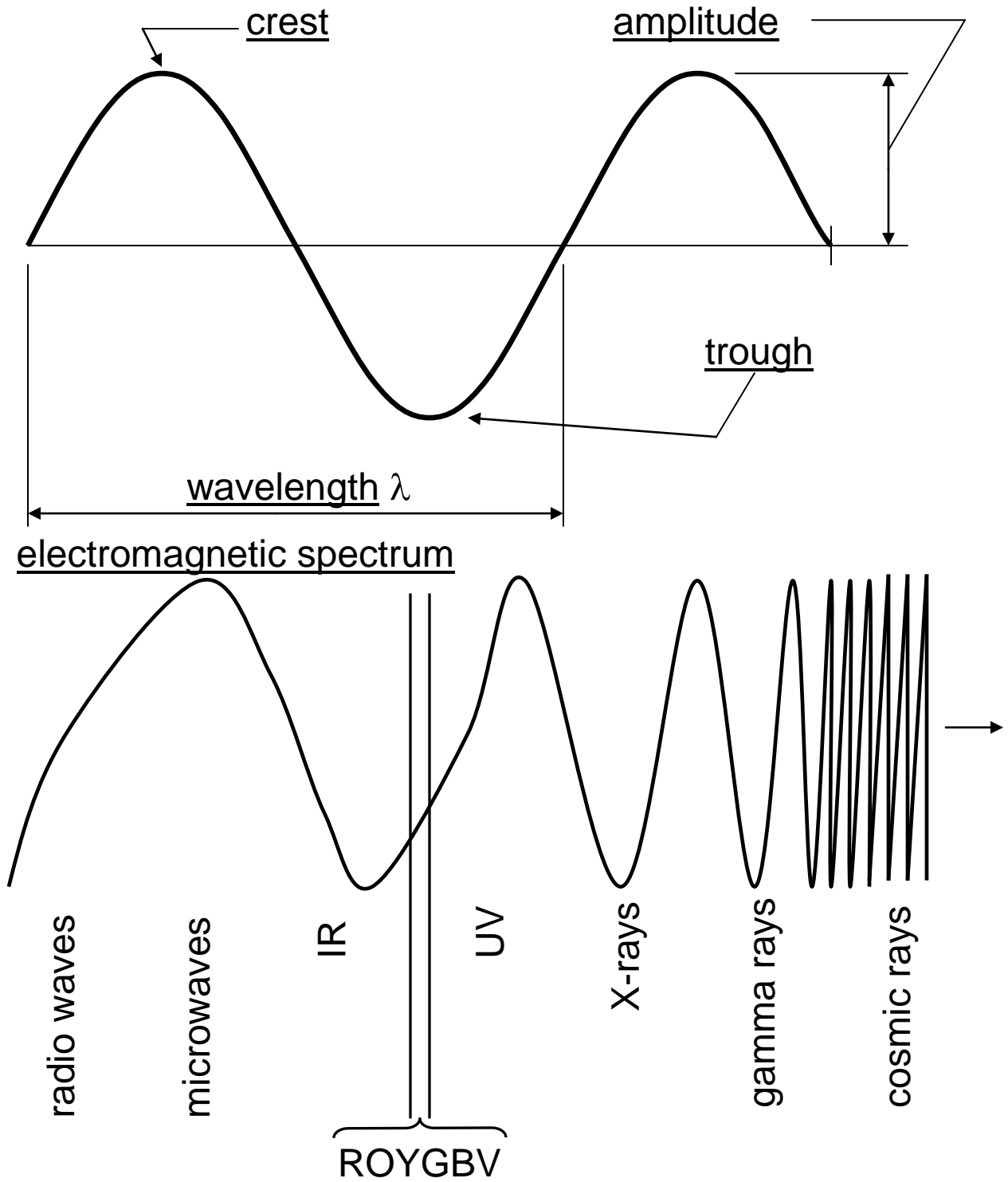
Lyman series:  $e^-$  falls to 1<sup>st</sup> energy level

Balmer series:  $e^-$  “ “ 2<sup>nd</sup> “ “

Paschen series:  $e^-$  “ “ 3<sup>rd</sup> “ “



# Light as a Wave



frequency: the # of wave cycles per second (Hz)

## Light as a Particle

photons: “bundles” of energy that make up light

In empty space (or air), all light has the same speed, but the amt. of energy depends on its frequency.

$c = f \lambda$  relates speed, frequency, and wavelength

where  $c$  = speed of light =  $3.00 \times 10^8$  m/s

$E = h f$  relates energy and frequency

where  $h$  = Planck's constant =  $6.63 \times 10^{-34}$  J/Hz

A photon has wavelength  $6.0 \times 10^{-7}$  m. Find its frequency.

$$c = f \lambda \rightarrow f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{6.0 \times 10^{-7} \text{ m}} = 5.0 \times 10^{14} \text{ Hz}$$

Find the energy contained in the photon above.

$$E = h f = 6.63 \times 10^{-34} \frac{\text{J}}{\text{Hz}} (5.0 \times 10^{14} \text{ Hz}) = 3.3 \times 10^{-19} \text{ J}$$

A photon carries  $6.6 \times 10^{-18}$  J of energy. Find its wavelength.

$$c = f \lambda \rightarrow f = \frac{c}{\lambda}, \text{ so } E = hf = \frac{hc}{\lambda} \text{ and } \lambda = \frac{hc}{E}$$

$$\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \text{ J/Hz} (3 \times 10^8 \text{ m/s})}{6.6 \times 10^{-18} \text{ J}} = \boxed{3.0 \times 10^{-8} \text{ m}}$$

**Isotopes** different varieties of an element's atoms  
 -- have diff. #'s of  $n^0 \rightarrow$  diff. masses  
 -- some are radioactive; others aren't

All atoms of an element react the same, chemically.

Isotope	Mass	$p^+$	$n^0$	Common Name
<b>H-1</b>	1	1	0	protium
<b>H-2</b>	2	1	1	deuterium
<b>H-3</b>	3	1	2	tritium

C-12 atoms

6  $p^+$ , 6  $n^0$

stable

C-14 atoms

6  $p^+$ , 8  $n^0$

radioactive

**Radioactive Isotopes:** have too many or too few  $n^0$

Nucleus attempts to attain a lower energy state by releasing extra energy as radiation.

e.g.,  $\alpha$ - or  $\beta$ -particles,  $\gamma$  rays

half-life: the time needed for  $\frac{1}{2}$  of a radioactive sample to decay into stable matter

e.g., C-14: -- half-life is 5,730 years

-- decays into stable N-14

Say that a 120 g sample of C-14 is found today.

<b>Years from now</b>	<b>g of C-14 present</b>	<b>g of N-14 present</b>
0	120	0
5,730	60	60
11,460	30	90
17,190	15	105
22,920	7.5	112.5

□ **Complete Atomic Designation**

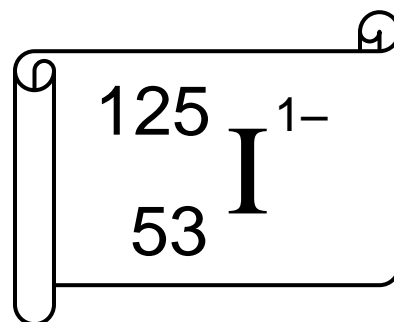
...gives precise info about an atomic particle

mass #

charge (if any)

element  
symbol

atomic #



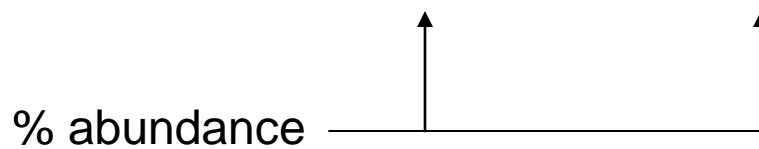
Protons	Neutrons	Electrons	Complete Atomic Designation
92	146	92	
11	12	10	
34	45	36	
			$^{59}_{27}\text{Co}^{3+}$
			$^{37}_{17}\text{Cl}^{1-}$
			$^{55}\text{Mn}^{7+}$

□ **Average Atomic Mass (Atomic Mass, AAM)**

This is the weighted average mass of all atoms of an element, measured in a.m.u.

For an element with isotopes A, B, etc.:

$$\text{AAM} = \text{mass A (\% A)} + \text{mass B (\% B)} + \dots$$



(use the decimal form of the %;

e.g., use 0.253 for 25.3%)

Lithium has two isotopes. Li-6 atoms have mass 6.015 amu; Li-7 atoms have mass 7.016 amu. Li-6 makes up 7.5% of all Li atoms. Find AAM of Li.

$$\text{AAM} = \text{mass A (\% A)} + \text{mass B (\% B)}$$

$$\text{AAM} = 6.015 \text{ amu (0.075)} + 7.016 \text{ amu (0.925)}$$

$$= \boxed{6.94 \text{ amu}}$$

\*\* Decimal number on Table refers to...

molar mass (in g) OR AAM (in amu).

6.02 x 10<sup>23</sup> atoms

1 "average" atom



Isotope	Mass	% abundance
Si-28	27.98 amu	92.23%
Si-29	28.98 amu	4.67%
Si-30		

$$AAM = \text{mass A (\% A)} + \text{mass B (\% B)} + \text{mass C (\% C)}$$

$$28.086 = 27.98 (0.9223) + 28.98 (0.0467) + X (0.031)$$

$$28.086 = 25.806 + 1.353 + 0.031X$$

$$X = \text{mass of Si-30} = \boxed{29.90 \text{ amu}}$$

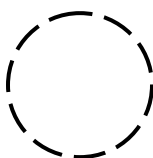
## Electron Configurations

### □ “e<sup>-</sup> Jogging” Rules

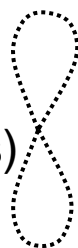
1. Max. of two e<sup>-</sup> per jogging track (i.e., orbital).

2. Easier orbitals fill up first.

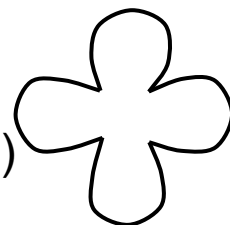
s orbital  
(level)



p orbital  
(rolling hills)



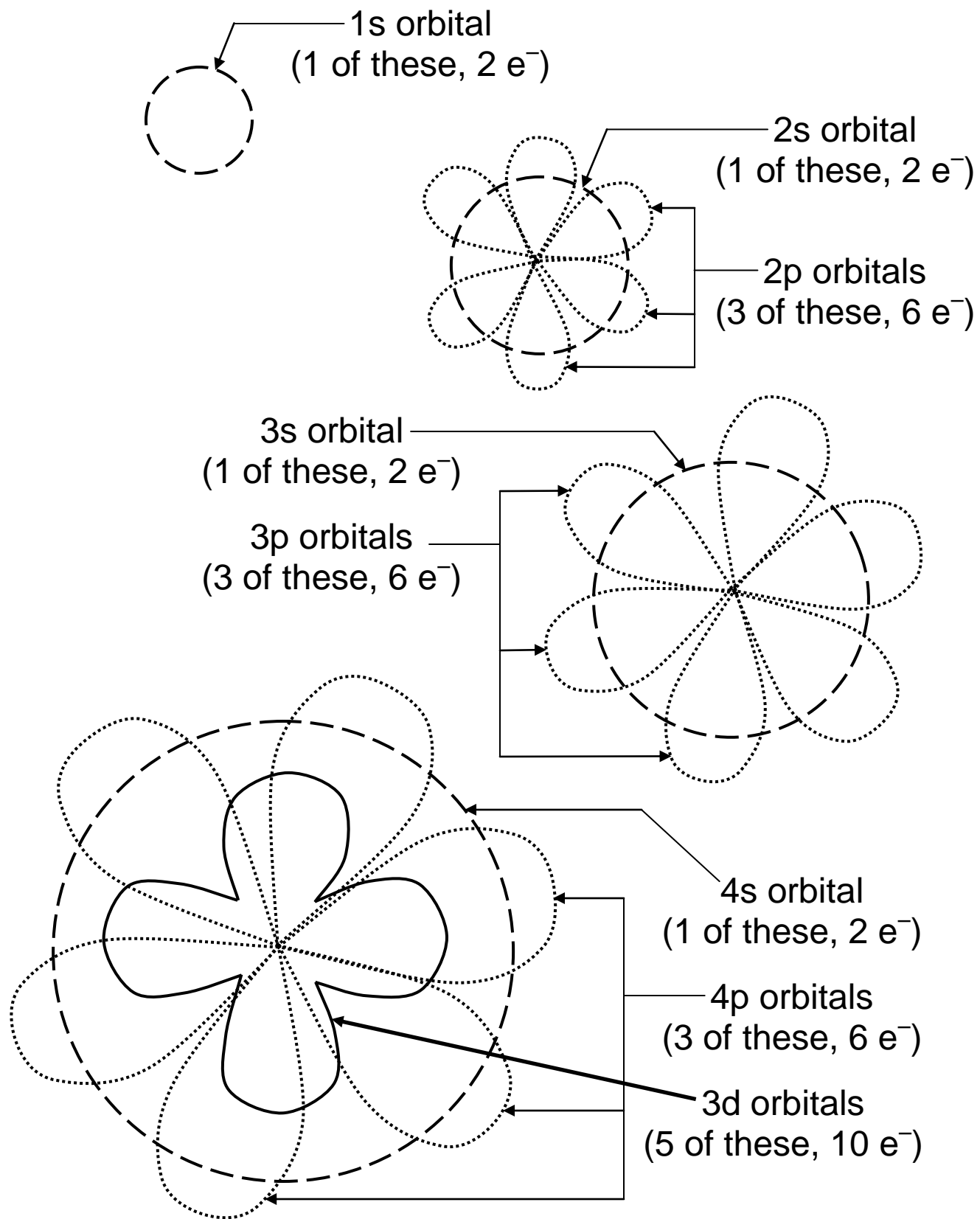
d orbital  
(steep hills)



3. e<sup>-</sup> must go 100X around.

4. All orbitals of equal difficulty must have one e<sup>-</sup> before any doubling up.

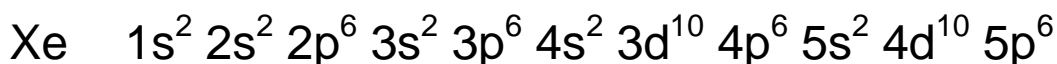
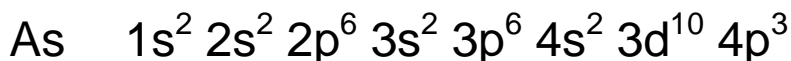
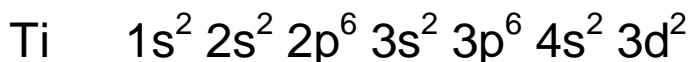
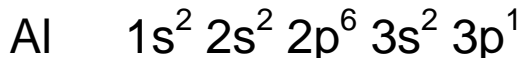
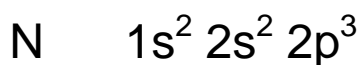
5. e<sup>-</sup> on same orbital must go opposite ways.



$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 \dots$

□ **Writing Electron Configurations**

Where are the  $e^-$ ? (probably)



□ **Three Principles about Electrons**

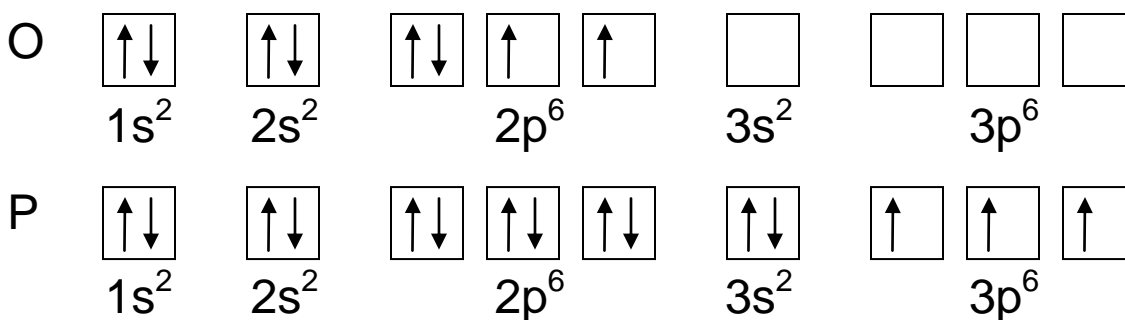
Aufbau Principle:  $e^-$  will take lowest-energy orbital available

Hund's Rule: for equal-energy orbitals, each must have one  $e^-$  before any take a second

Pauli Exclusion Principle: two  $e^-$  in same orbital have different spins

□ **Orbital Diagrams**

...show spins of e<sup>-</sup> and which orbital each is in



□ **Sections of Periodic Table to Know:**

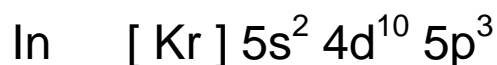
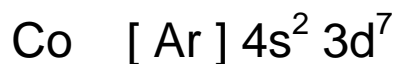
s-block, p-block, d-block, f-block

□ **Shorthand Electron Configuration (S.E.C.)**

To write S.E.C. for an element:

1. Put symbol of noble gas that precedes element in brackets.

2. Continue writing e<sup>-</sup> config. from that point.



## □ ***The Importance of Electrons***

In “jogging tracks” analogy, the tracks represent orbitals: regions of space where an  $e^-$  may be found

In a generic  $e^-$  config (e.g.,  $1s^2 2s^2 2p^6 3s^2 3p^6 \dots$ ):

coefficient → # of energy level

superscript → # of  $e^-$  in those orbitals

In general, as energy level # increases,  $e^- \dots$

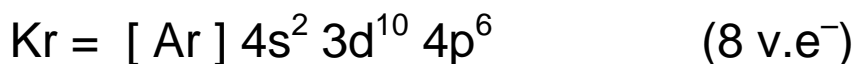
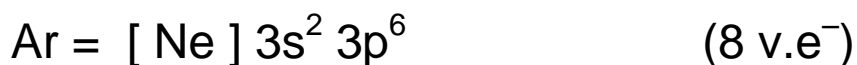
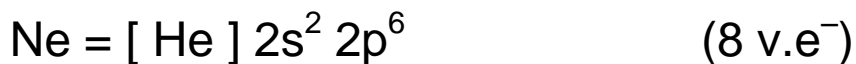
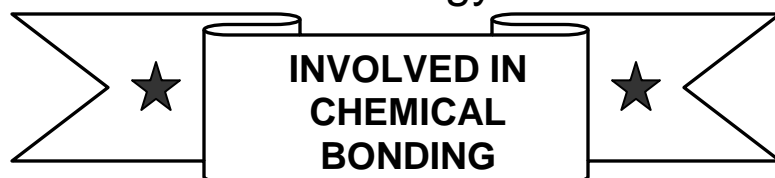
HAVE MORE  
ENERGY

AND

ARE FARTHER  
FROM NUCLEUS

kernel electrons:  
in inner energy level(s);  
close to nucleus

valence electrons:  
in outer energy level



octet rule: the tendency for atoms to “want” 8  $e^-$

in the valence shell (NOT H, He, Li, Be, B)

Noble gas atoms have full valence shells. They are stable, low-energy, and unreactive.

Other atoms “want” to be like noble gas atoms.

They give away or acquire  $e^-$ .

fluorine atom, F

$9 p^+, 9 e^-$



Lose  $7 e^-$  or steal 1?



$9 p^+, 10 e^- \rightarrow F^{1-}$

F atom would rather  
be  $F^{1-}$  ion.

chlorine atom, Cl

$17 p^+, 17 e^-$



Lose  $7 e^-$  or steal 1?



$17 p^+, 18 e^- \rightarrow Cl^{1-}$

Cl atom would rather  
be  $Cl^{1-}$  ion.

lithium atom, Li

$3 p^+, 3 e^-$



lose  $1 e^-$

$3 p^+, 2 e^- \rightarrow Li^{1+}$

sodium atom, Na

$11 p^+, 11 e^-$



lose  $1 e^-$

$11 p^+, 10 e^- \rightarrow Na^{1+}$

Know charges on these columns of Table:

Group 1:	1+	Group 15:	3-
Group 2:	2+	Group 16:	2-
Group 13:	3+	Group 17:	1-
		Group 18:	0

## Naming Ions

Cations → use element name and then say “ion”

e.g.,	$\text{Ca}^{2+}$	calcium ion
	$\text{Cs}^{1+}$	cesium ion
	$\text{Al}^{3+}$	aluminum ion

Anions → change ending of element name to

“ide” and then say “ion”

e.g.,	$\text{S}^{2-}$	sulfide ion
	$\text{P}^{3-}$	phosphide ion
	$\text{N}^{3-}$	nitride ion
	$\text{O}^{2-}$	oxide ion
	$\text{Cl}^{1-}$	chloride ion